Thin Film Solar Cells Program in Japan
-Achievements and Challenges -

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ABSTRACT

The results of the Japanese four-year thin film solar cell program, which was initiated in 1997, were recently reviewed and evaluated. The evaluation showed that substantial progress was made in thin film technology in the past four years and the almost all targets were met as of March 2001. As a result of the wide-ranging break-throughs achieved during the past four-year program, a new five-year program has been initiated from FY2001 aiming at more challenging targets. The major part of this program is the development of large area Si based thin film solar cells and CIGS thin film solar cells with efficiencies over 12% and 13%, respectively.

1. Targets and Achievements in the Four Year Program (1997-2001)

Table 1 shows the major research and development (R&D) targets and achievements for the Japanese four-year thin film solar cells program between 1997-2000. In this program, the targets were to reduce module costs and improve efficiency, where the former of the two aims was set assuming an annual output of 100MW/year.

In the area of amorphous Si, the establishment of a technical basis for a method of manufacturing low-cost, high efficiency a-Si solar cell modules was a major part of this program and achieved steady results. In the "Glass substrate" program (SANYO), the recent optimization of processes led to a highly stabilized efficiency of 10.0% for a 8252 cm^2 a-Si/a-SiGe tandem module, where the top a-Si and bottom a-SiGe layers were deposited at 0.3nm/s. In the "Flexible module"program(Fuji), a stabilized aperture area efficiency of 9.2% was obtained for a-SiGe/a-Si SCAF (Series-Connection through Apertures formed on Film) cells. In the area of CdS/CdTe thin film solar cells, an aperture area (5413 cm^2) efficiency of 11.0% was achieved (Matsushita Battery).

The most remarkable improvement in CIGS thin film solar cell efficiency has been the 18.5% efficient device achieved by Matsushita Electric. A major breakthrough has been achieved by in-situ monitoring of the surface temperature during growth. Showa Shell Sekiyu has proposed a Zn-compound that contains sulfur as one alternative for Cd-free buffers. A sub-module efficiency of 12.93% (30cmx30cm) was achieved for a device structure consisting of ZnO/$Zn(O,S,OH)_x$ /CIGS/Mo/glass substrate.

In the "Zone-Melting Recrystallization" program (Mitsubishi), polycrystalline Si thin film solar cells with high efficiencies of 14.6% were obtained for a mini-module of 20cmx30cm with a thickness of 77 μm. The polycrystalline Si films were also grown on carbon substrate by liquid phase epitaxy without any seed crystals. To-date, an efficiency of 12.2% has been achieved for a 4.34 cm^2 area cell (Air-Water).

Significant progress was made in research on thin film Si stacked solar cells. It was possible to deposit polycrystalline Si thin film solar cells having a thickness of several μm by plasma CVD at low temperatures. An initial efficiency of 11.7% (4141cm^2) for a-Si/poly-Si hybrid-type thin film solar cells was achieved by KANEKA. Production technologies for the a-Si/Si-sheet hybrid solar cells have been developed by Sharp. Up to now, an efficiency of 12.0% has been obtained (1cm^2). A single crystal Si thin film solar cell proposed by Sony showed an efficiency of 12.5% for cell areas of 4 cm^2.

2. PV Roadmap toward Year 2030

Figure 1 shows the long-term targets for developing large-scale PV power generation technology in the 21st century. The target by year 2030 is the development of technology for the production of electricity at a cost of 5-6 Yen/kWh, which corresponds to the electricity generation cost of present-day nuclear and fossil fuel power generation systems. To meet these challenging goals toward Year 2030, the development of novel solar cells such as dye-sensitized cells and a novel semiconductor material solar cell will be studied as well conventional solar cell materials.

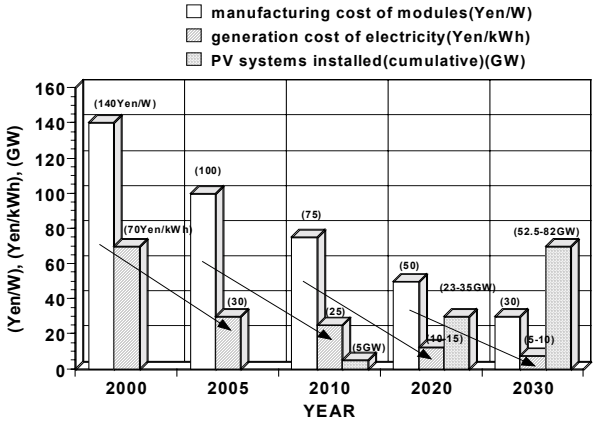

Fig. 1 PV roadmap toward Year 2030. The arrows in the figure indicate the technology transfer from the R&D phase to the practical application.

3. A New Five-Year Program (2001-2005)

To achieve the long-term targets, a new five-year program was initiated from FY2001 aiming at more challenging targets. The research theme and major targets are shown in Table 2. The budget for this program in FY2001 is 5 Billion Yen.

Table 1. Major Targets and achievements under the New Sunshine Program (1997-2000).

Theme	Targets by FY2000	Achievements
Manufacturing technology of new type amorphous and high-reliability CdTe PV module		
a-Si modules, Glass sub.	η*=10%, 140yen/W, 90cmx90cm	η*=10.0%, 133yen/W, a-Si/a-SiGe, 8252cm^2
a-Si modules, Flexible	η*=10%, 140yen/W, 40cmx80cm	η*=9.2%, 147yen/W, a-Si/a-SiGe, 40cmx80cm
CdTe module	η*=13%, 140yen/W, 60cmx90cm	η=11.0%, 140yen/W, 5413 cm^2
Manufacturing technology of advanced thin-film PV module		
CIGS by selenization	η=13%, 140yen/W, 30cmx30cm	η=12.9%, 137yen/W, 30cmx30cm
CIGS by evaporation	η=16%, 10cmx10cm	η=12.6%,10cmx10cm, 18.5%,1cm^2
ZMR poly-Si thin film	η=15%, 140yen/W, 30cmx30cm	η=14.6%, 137yen/W, 600cm^2 ,77μm
LPE poly-Si thin film	η=13%, 10cmx10cm	η=12.2%, 4.34cm^2
a-Si/poly-Si hybrid	η=14%, 5cmx5cm	η*=11.7%, 910x455mm^2, η*=14.1%, 1cm^2
a-Si/poly-Si sheet hybrid	η=14%, 5cmx5cm	η*=12.0%, 1cm^2
Single crystal Si thin film	η=14%, 5cmx5cm	η=12.5%, 2cmx2cm^2 ,12μm
Micro-concentrator	η(cell)=15%,4mm^2, η(module)=14%, 25cm^2,140yen/W	η(cell)=15.3%,4mm^2,η=14.02%,2.7suns, 138yen/W
Development of manufacturing technology of new materials and substrates		
High quality a-Si materials	2nm/s, N_D*=2.5x10^{16}/cm^3	2nm/s, N_D*=2.0x10^{16}/cm^3
High quality μc-Si	1nm/s, N_D=1x10^{16}/cm^3	1nm/s, N_D=1x10^{16}/cm^3, η=9.4%(140□)
Development of manufacturing technology of ultra-high efficiency crystalline compound solar cell		
III-V mechanical stack	η=30%(on GaAs), 5cmx5cm	η=30.3%(GaAs/GaInAs), 5cmx5cm η=31.1%(GaAs/GaInAsP), 1cmx1cm
III-V on Ge	η=30%(on Ge), 5cmx5cm	η=31.2%(InGaP/InGaAs/Ge), 5cmx5cm
III-V on Si	η=25%(on Si), 5cmx5cm	η=17.85%(GaAs on Si), 5mmx5mm

η*: stabilized efficiency, N_D*:defect density after light soaking

Table 2. Outline of Research and Development under the New Sunshine Program from FY2001.

(1)Development of advanced solar cell modules		
Theme	Research Institute	Target*(2001-2005)
Si-based thin film solar cell modules		
High efficiency a-Si/poly-Si hybrid module	Kaneka	η=12%, 100yen/W, 3600 cm^2
High quality Si-based thin film	Mitsubishi Heavy Industries	(prototype module)
CIS based thin film solar cell modules		
High quality CIGS module	Showa Shell Sekiyu	η=13%, 100yen/W, 3600 cm^2
High throughput CIGS module	Matsushita Electric	(prototype module)
Ultra-high efficiency compound solar cells		
Concentrator cell	Sharp	η=40%(concentrator)
Concentrator module	Daido Steel	100yen/W
Concentrator system	Daido Metal	
High-efficiency multi-crystalline Si(cast Si) solar cells	Kawasaki Steel, Sumitomo Metal, Sharp	(1999–2003) η=20%, 15cmx15cm,147yen/W

(2)Development of evaluation , recycling and other infrastructure technologies	
Theme	Research Institute
Evaluation techniques of solar cells and modules	AIST**, JET***
Evaluation techniques of PV system	AIST, JET
Development of recycling and reuse techniques	Sharp, Showa Shell, Asahi Glass, AIST, PVTEC
Research on electromagnetic environment in PV system	JET

(3)Development of innovative, next-generation PV system	
Theme	Research Institute
$CuInS_2$ thin film solar cell by electroplating	Sinko Electric
Nano-strucure Si thin film solar cell	AIST,Kyushu Univ. Toppan Printing,Stanley,Nippon Sheet Glass
SiGe-based solar cell	Tohoku Univ.
Solid state dye-sensitized cell	Univ.Tokyo,□RITE
Low cost manufacturing technique by CAT-CVD	JAIST, Osaka Univ.,Gifu Univ.
β-$FeSi_2$ solar cell	System Engineers, AIST
Ultra-efficient optical confinement	Asahi Glass
Silicon ball solar cell	Clean Venture 21
Low cost and high efficiency dye-senstized cell	AIST, Sumitomo Osaka Cement, Furukawa, Hayashibara Biochemical Lab. Sharp

* Cost target: under the condition of over 100MW/year production
** National Institute of Advanced Industrial Science and Technology
*** Japan Electrical Safety & Environment Technology Laboratories